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Application of 3D Reservoir Modeling on Zao 21 Oil Block of Zilaitun Oil Field

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Abstract

Reservoir modeling is an effective technique that assists in reservoir management as decisions concerning development and depletion of hydrocarbon reserves must be taken considering the uncertainties of the formation involved. The paper focuses on the use of Petrel Software to construct a 3D-dimensional reservoir model that characterizes and evaluate Zao 21 block reservoir located in Dagang Oil field zilaitun area in Hebei Province of China which has an oil bearing area of 0.9 km^2.

The approach is based on integration of data from seismic, well logs of 41 wells obtained from geology, geophysics, petrophysics, to characterize and provide an accurate description of the internal architecture and visualization of reservoir heterogeneity. These data are used to build the lithofacies, porosity, permeability and oil saturation model which are the parameters that describe the reservoir and provide information on effective evaluation of the need to develop the potential of the remaining oil in the reservoir. The lithological facies architecture is simulated using Sequential Indicator Simulation to guide the distribution of petro-physical properties of the reservoir since they are intimately related. In addition, the petro-physical parameters are simulated using Sequential Gaussian Simulation. The reservoir structural model shows system of different oriented faults which divided the model into two segments, the major and minor segments.

Statistical analysis of the Porosity model, permeability model for Zao 21 block showed that porosity is mainly concentrated between 12.5% to 22.5% with an average porosity of 15.5%; and permeability mainly between 40 mD~ 110 mD, with a mean permeability of 81 mD; overall good reservoir properties. The estimation of these values was used to quantify the geological reserve of Zao 21 reservoir block oil deposit.

This study has shown the effectiveness of 3D reservoir modeling technology as a tool for adequate understanding of the spatial distribution of petro-physical properties and in addition framework for future performance and production behavior of Zao 21 block reservoir.

The reservoir model reveals that the reservoir properties of the north-eastern part of the oil field are very promising and wells should be drilled to investigate and exploit the oil.

Keywords: 3D reservoir modeling; Characterize; Heterogeneity; Porosity; Permeability; Oil saturation

Introduction

The demand for oil product has placed huge effort on the search for oil with development in Technology to assess the certainty of hydrocarbon, reducing the risk associated with hydrocarbon. Many Government of oil producing countries rely on money generated from oil and their products. It is essential to model the reservoir as accurately as possible in other to calculate the reserves and to determine the most effective way of recovering as much of the petroleum economically as possible. In addition it enables for 3D visualization of the subsurface, which improves understanding of reservoir heterogeneity and helps to enhance oil recovery. To build this model an understanding of the data integrity was done as well as the reservoir with its host rock. In other to drill to the target, 3D seismic data interpretation and well data were used to build a 3D reservoir model that would make the data more reliable [1-5].

Geological location

The Zao 21 Block is located on Zilaitun area of Dagang oil field, Hebei Province Huanghua Depression area which belongs to a tectonic unit of Bohai Bay basin in the east of China which is the biggest depressed area. It has an oil-bearing area 0.91 km^2. The block reservoir is controlled by some fault systems trending NE and NS and characterized by lithology mainly fine sand, siltstone and some shale content [6-9], (Figure 1).

Sedimentary facies

Zao 21 block store group a for shallow water delta deposits, work area is mainly delta front subfacies. Delta front mainly developed underwater distributary channel, distributary bay, mouth bar sedimentary microfacies [9-12].

The space is little, the study area well pattern density (57) 1.6 km^2 area of well spacing, thickness, single well facies classification larger workload, underwater distributary channel microfacies, reservoir area development so choose sand mudstone facies model for sand control constraint modeling instead of a phased modeling of sedimentary facies [12-18].

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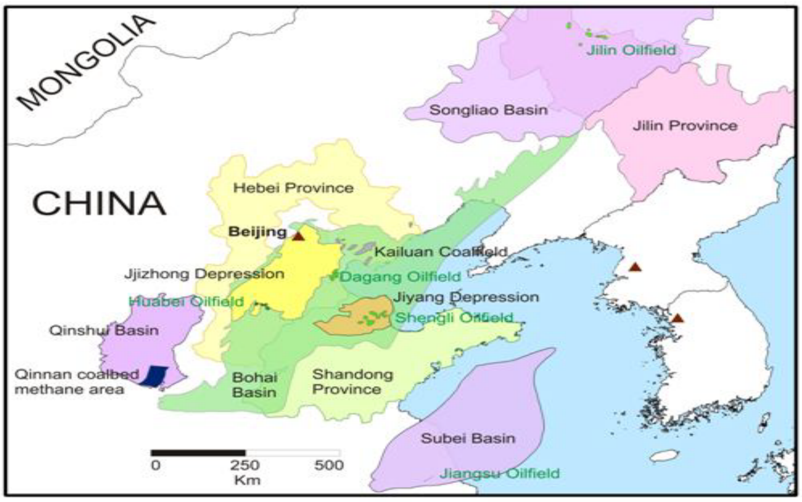

Figure 1: Location map of the study area.

The Modeling Approach

Reservoir model

In view of the necessity of dynamic simulation process and to arrive at a final well and production behavior, it was necessary to build a reservoir model that represented as closely as possible the sub-surface reality of Zao 21 block that have been encountered by most wells. The model of Zao 21 for the entire Zao 21 block in Dagang formation was built by integrating relevant sub-surface data and interpretation presented in the preceding sections. The seismic structural interpretation, lithological descriptions and facies interpretation, porosity, permeability and initial oil saturation from log analysis were used to build the reservoir model. The PETREL (Version 2009.1) suite was used in building the reservoir model. The structural and property model of the reservoir are briefly described as follows [19-22].

Structural Model

The structural model was based on seismic interpretation data. The input data consist of fault polygons and fault surfaces of interpreted faults. Fault modeling was the first step for building structural models with Petrel workflow tools (Figure 2) [23-28]. The process was used to create structurally and geometrically corrected fault interpretation within the horizon. The faults divided the model into 2 segments. Pillar gridding is a way of storing XYZ location to describe a surface which was used to generate a 3-D framework. A 3D-grid divided the space up into cells within which it assumed materials were essentially the same. The next step is Make Zones process in defining the vertical resolution of the 3D grid. The process creates zones between each horizon. The areal dimension of the grid cells was optimized at 50 × 50 m considering the reservoir description in Zao 21 prospect. The 3D reservoir model contained 22230 cells. Figures 3-19 shows the structural model of Zao 21 block [29-35].

Property modeling

Facies modeling: Facies modeling is an important aspect of the modeling process. The purpose is to simulate the sand bodies in the formation. The oil field is composed of mainly fine sandstone, silt stone and some amount of shale content [36-41]. The lithofacies were defined and calculated. The method of most of was used to average

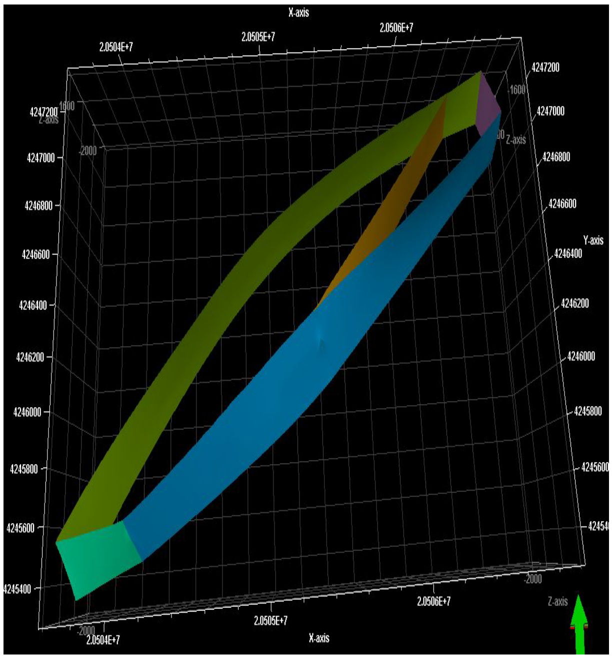

Figure 2: 3DFault model.

the facies. Sequential Indicator Simulation method was applied to simulate the sand bodies in the formation. The proportion of fine sand, silt and clay were 51.42%, 19.60% and 28.98%. This is stochastic method that combines variograms and target volume fractions. It is most appropriate with minimal well data, when either the shape of particular facies bodies is uncertain. It also allows easy modeling of facies environment where facies volume proportion vary vertically, laterally or both. Figure 6 shows the Lithofacies model.

Petrophysical modeling

Porosity model: Porosity is an essential property of an oil reservoir that determines the capacity of oil it can contain. The porosity model is based on porosity logs generated from the petrophysical interpretation of 41 wells. The well logs were scaled up using the method of arithmetic

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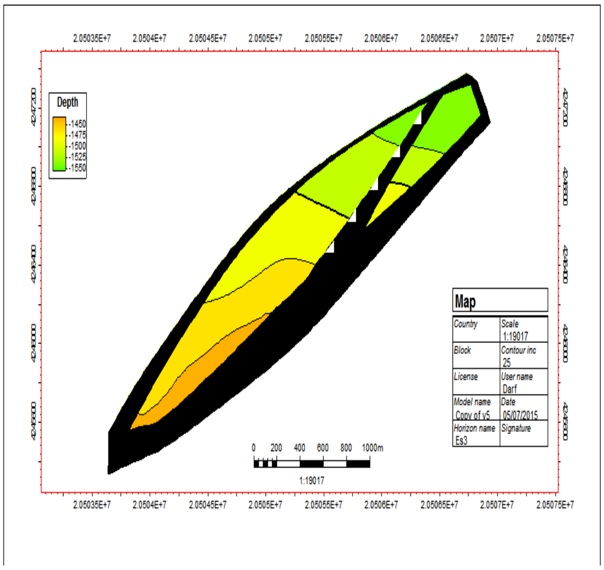

Figure 3: 2D map of Top horizon.

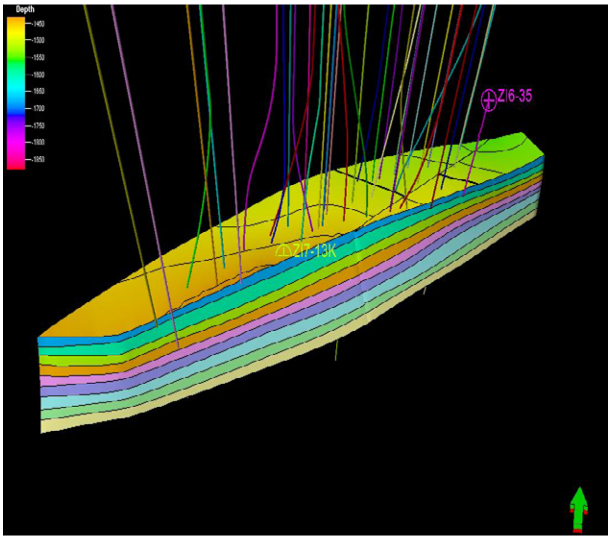

Figure 4: 3D Structural model.

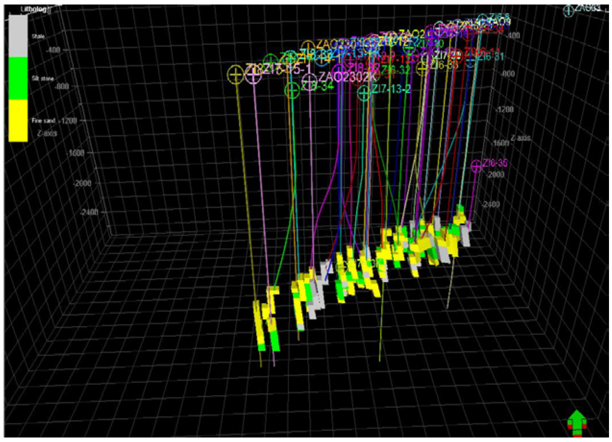

Figure 5: scaled up of lithology.

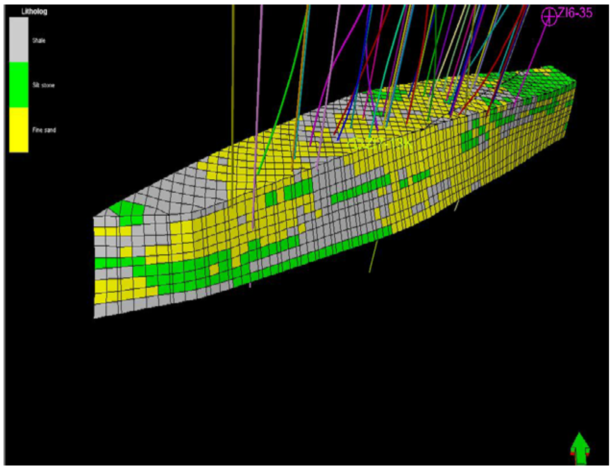

Figure 6: 3D Lithology model.

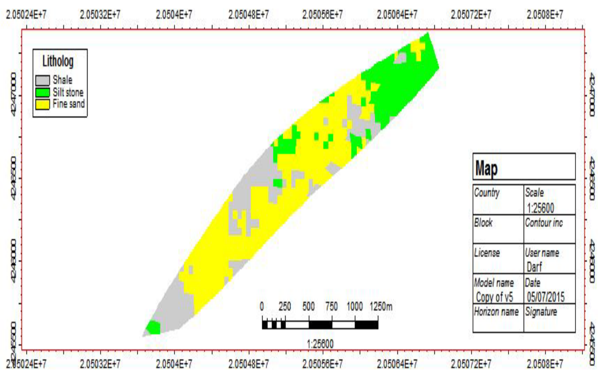

Figure 7: 2D Lithology map.

averaging. The porosity was distributed in the model using Sequential Gaussian simulation method. Data analysis tool provided variogram calculation and data transformation. This attribute is controlled by the distribution of Lithofacies in the reservoir. The porosity distribution is mainly concentrated between 12.5%-22.5% with an average porosity of 15.5%. Figures 8-10 show the scaled up porosity logs, porosity model and histogram showing the distribution.

Permeability model: Permeability is an essential characteristic of a Petroleum reservoir rock. It is a property of the porous medium that measures the capacity and ability of the formation to transmit fluids. The rock permeability is very important rock property because it controls the directional movement and the flow rate of the reservoir fluids in the formation [42]. The well logs were scaled up using harmonic averaging. Sequential Gaussian Simulation method was used. As a result of the relationship between permeability and porosity, in the permeability modeling process, porosity was used as secondary variable. The method of collocated co-kriging was used which provides additional control parameter; the correlation coefficient between the primary and secondary variable. The permeability model shows that permeability of Zao 21 block is mainly concentrated between 40 mD~

110 mD, having an average permeability of 81 mD. The permeability model and histogram distribution of the scaled up and well logs are shown in Figures 11 and 12.

Saturation model: Even though saturation is not important as porosity and permeability, saturation distribution model helps to identify potential high water area. Saturation is the fraction of oil, water, and gas found in a given pore space. This is expressed as a volume/volume percent of saturation units. Typical saturation analysis does not show 100% fluid saturations due to the volume expansion and fluid loss associated with bringing a subsurface core with typical higher temperatures and pressures to the surface with lower temperatures and pressures. To determine the quality of hydrocarbons accumulated in a

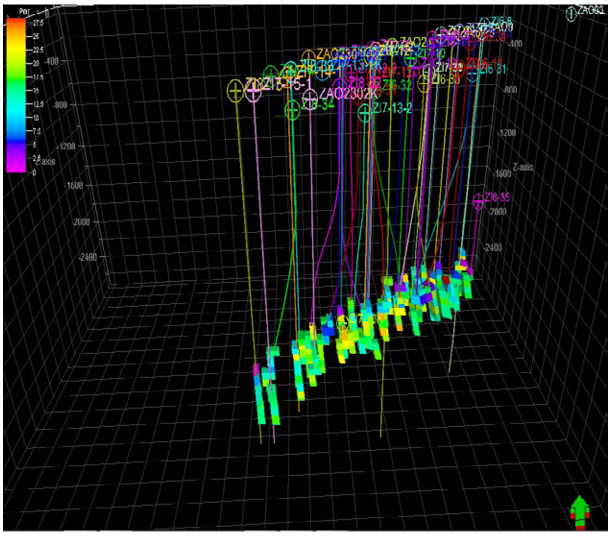

Figure 8: scaled up porosity log.

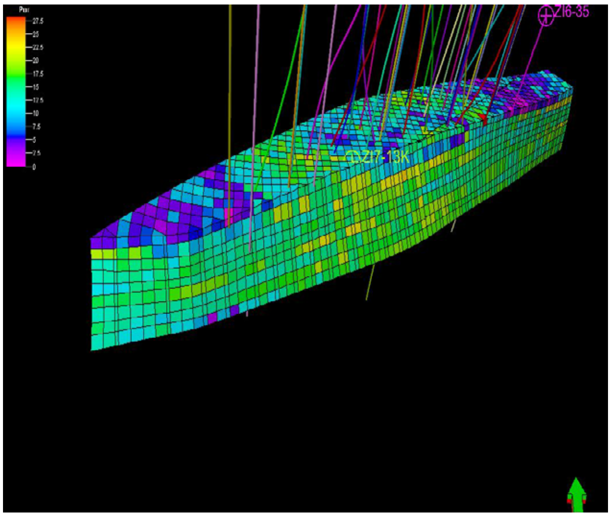

Figure 9: 3D Porosity model.

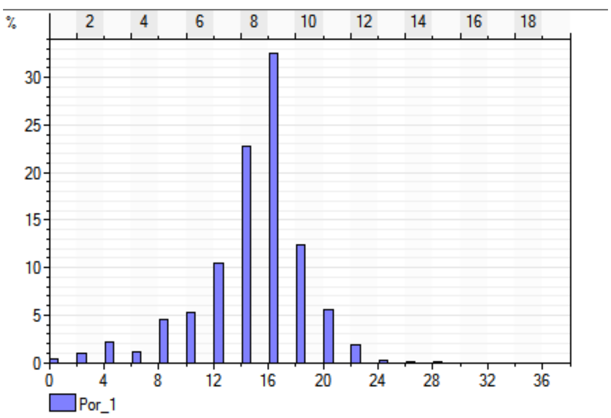

Figure 10: Histogram of porosity distribution.

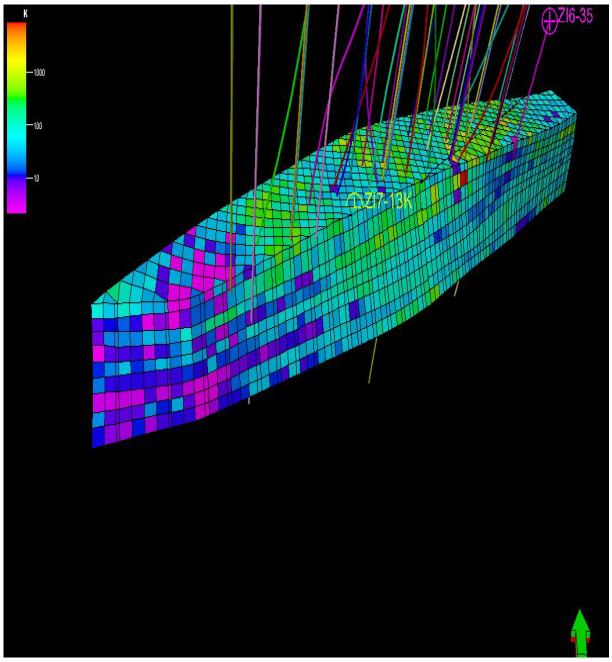

Figure 11: 3D Permeability model.

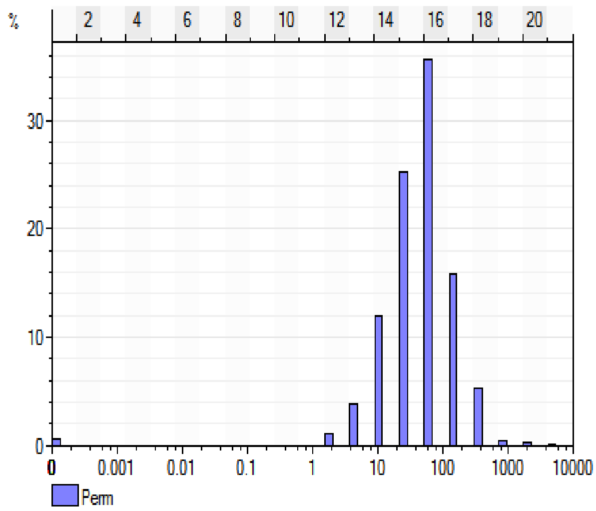

Figure 12: Histogram of permeability distribution.

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porous rock formation, it's necessary to determine the fluid saturation (oil, water and gas) of the rock material. This study modeled the oil saturation of Zao 21 block which is shown in Figure 13. The method of arimethic averaging was used to scale up the well logs.

Porosity-permeability relationship of Zao 21 block: The amount of porosity is principally determined by shape and arrangement of sand grains and the amount of cementing material present, whereas permeability depends largely on size of the pore openings and the degree and type of cementation between sand grains. Although many formations show a correlation between porosity and permeability, the several factors influencing these characteristics may differ widely in effect, producing rock having no correlation between porosity and permeability.

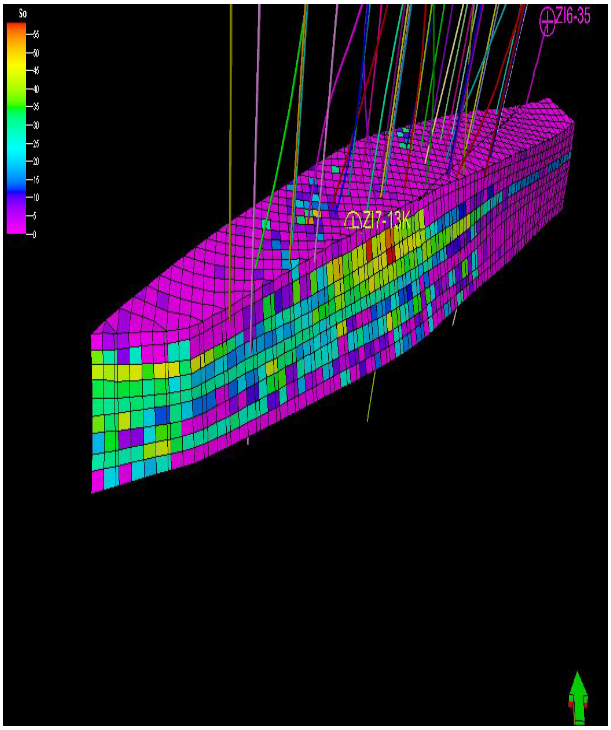

Figure 13: 3D Oil saturation model.

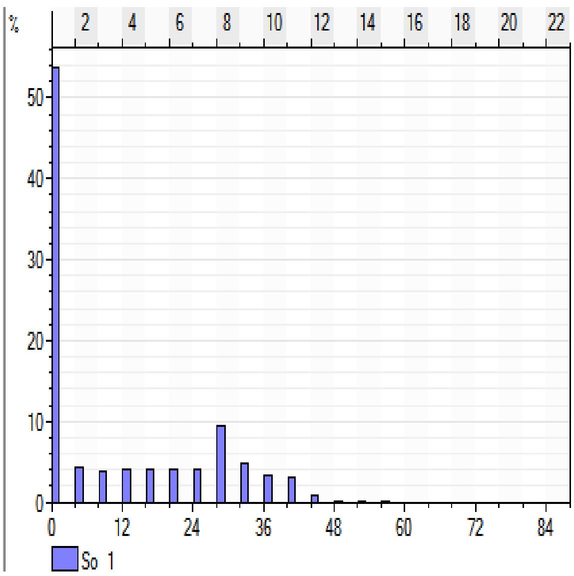

Figure 14: Histogram of oil saturation Distribution.

A cross plots of porosity-permeability of upscaled cells of Zao 21 block shows a strong correlation. The regression line is given by; $logK = 0.120\Phi - 0.989$.

Figure 15 shows a porosity-permeability cross plot for Zao 21 reservoir, where diagenetic effect is minimal at the reservoir depth resulting in some degree of heterogeneity. A correlation analysis between these two petrophysical parameters was done using a single cross-plot. Correlation coefficient for this method is 0.844.

Upscaling

High resolution Reservoir description models cannot be used directly to perform reservoir simulation study due to limitation of computer memory and speed. It is necessary to scale the high resolution reservoir description model to the coarser resolution of the production simulation. The result preserves representative simulation behavior. A grid dimension of 100 × 100 was used. Figures 16 and 17 shows the up scaled models.

Reservoir Volumetric

Reservoir volumetric is the process by which the quantity of hydrocarbon in a reservoir is estimated. This is very important because the exploration and development. After the reservoir model of Zao 21 was done (Table 1), the structural model and petro physical model built were used to calculate the reserves in terms of stock tank oil originally in place (STOIIP). Zao 21 block were estimated using the equation below.

$$STOIIP = 7758 \times A \times h \times \varnothing \times (1 - Sw) \times 1 / Bo$$

However, according to the 3D reservoir model, the following parameters were also calculated;

- Formation volume
- Hydrocarbon reservoir pore volume
- The volume of oil reserves

Results and Discussion

Interpretation and results

A. Structural model of Zao 21 block

Figure 4 indicates the system of different oriented growth faults with two major faults trending towards NE and NS. The other faults are categorized as minor faults. This model further buttresses the information gathered from the depth structural map.

B. Porosity model

A 3D perspective view of the porosity model is shown in Figure 9.

Fluid Properties	Parameters
Density of ground water	1.0 g/cm^3
Oil density at reservoir condition	0.949 g/cm^3
Crude oil formation volume factor at reservoir condition	1.114
Oil viscosity at reservoir condition	45.6 mPa.s

Table 1: Zao 21 Reservoir fluid properties parameters.

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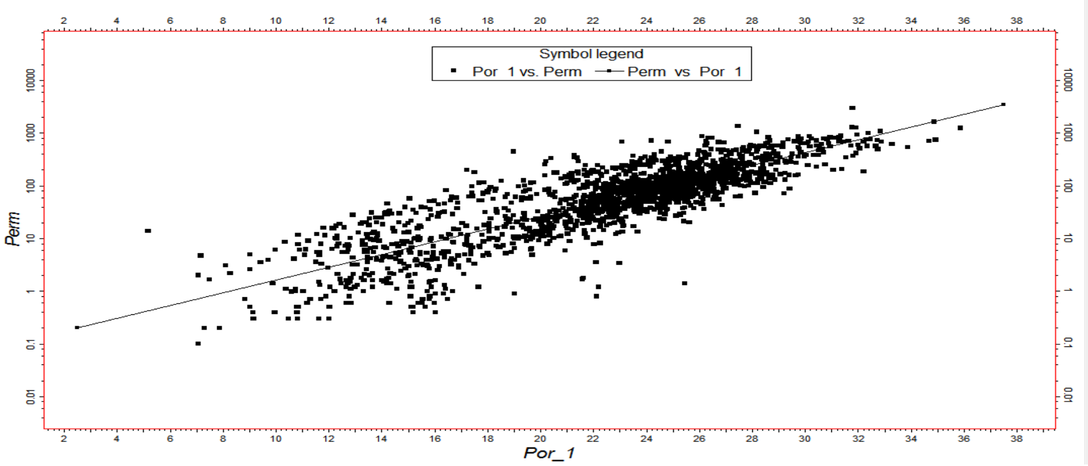

Figure 15: Porosity and Permeability relationship using scaled up well logs.

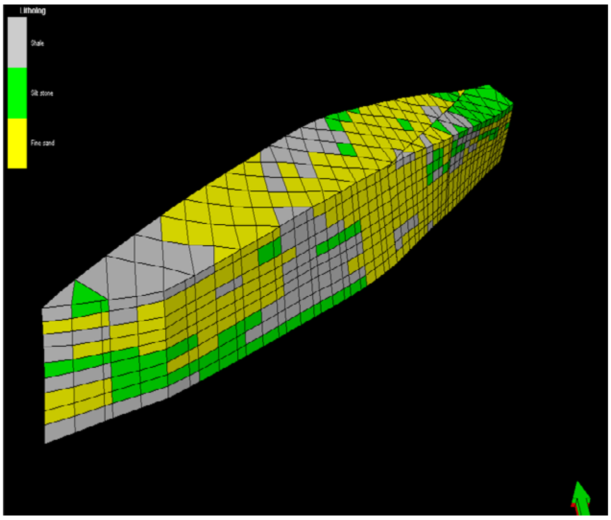

Figure 16: Upscaled Lithology model.

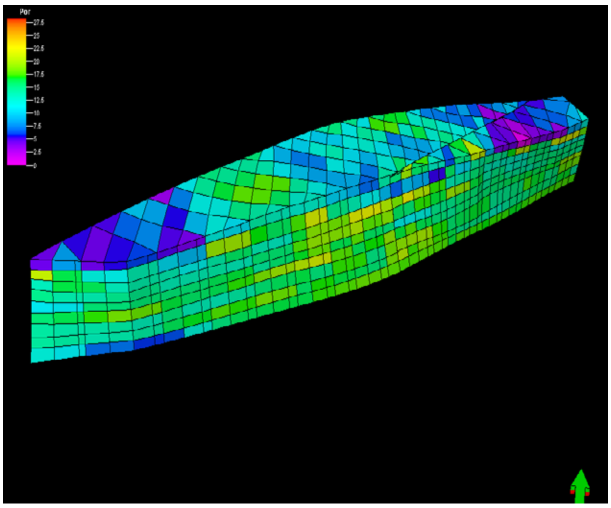

Figure 17: Upscaled Porosity model.

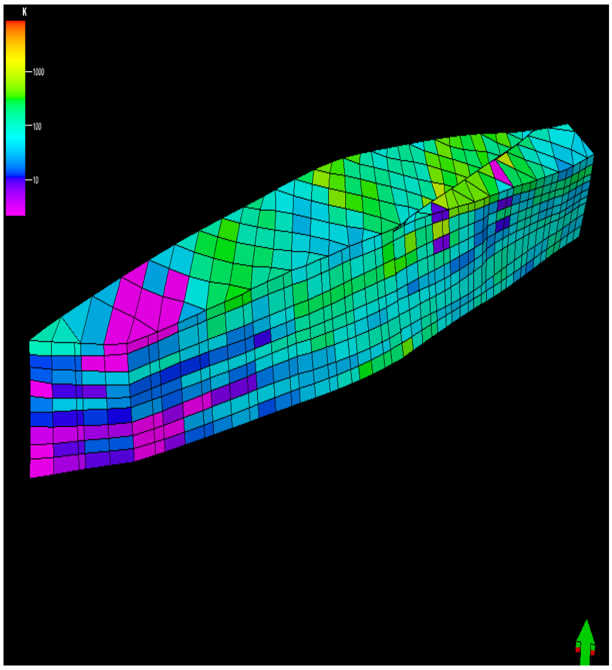

Figure 18: Upscaled Permeability model.

The formation porosity map shows the prominence of good porosity distribution which is mainly concentrated between 12.5%-22.5% of Zao 21 block. The central portion shows high porosity distribution. This indicates that the pore spaces have enough space to accommodate fluid. However, on a whole the average porosity value is 15.5% and according to Levorsen, it is a good reservoir rock as shown in Table 2.

A. Permeability model

Figure 11 shows a 3D perspective view of the permeability model. The map underscores a permeability concentrated mainly between 40 mD to 110 mD shown in Figure 12 within the well areas of Zao 21 block with an average permeability of 81 mD within Zao 21 oil field. The value is a reflective of good connectivity of pore spaces of sand and their ability to transmit fluids. According to Levosen, it is a good

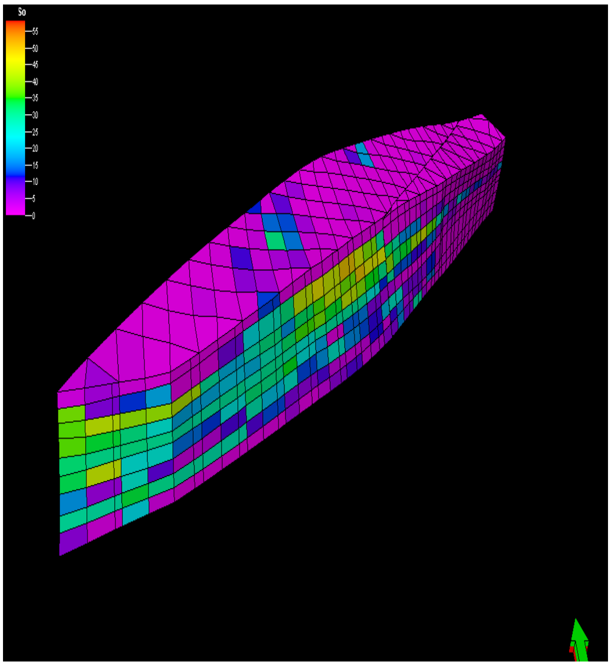

Figure 19: Upscaled oil saturation model.

Zones	Bulk Volume [x10^6 m^3]	STOIIP (in oil) [x10^6 m^3]
Zone 1	54.893112	0.646922
Zone 2	56.692663	0.668130
Zone 3	57.793266	0.681101
Zone 4	61.500136	0.724787
Zone 5	56.910949	0.670703
Zone 6	66.492047	0.783617
Zone 7	88.441250	1.042291
Zone 8	68.723252	0.809912
Zone 9	78.791877	0.928572

Table 2: Volumetric calculation results.

reservoir rock as shown in Table 3.

B. Oil Saturation model

Figures 3-8 shows a 3D perspective view of the oil saturation. The model reveals that the oil saturation distribution on Zao 21 block is highest (yellow, green to orange) at the central part (0.3-0.45) of the oil field than at the north eastern and south western. However, relatively, the north-eastern part shows better oil saturation than south-western part of the reservoir model.

C. Lithofacies model

A 3D perspective view of the facies model is shown in Figure 6. The model shows that the dominant face at the south-western part is dominated by fine sand. The central part shows a mixture of three facies, silt sand, fine sand and small proportion of shale while the north-eastern part shows good proportion of sand and clay with a small fraction of silt sand. The south-western part shows a good distribution of sand, however, the oil saturation is relatively low compared to the central part. This may be attributed to the diagentic factors in the formation.

Porosity (Φe, %)	Qualitative Evaluation
0-5	Negligible
5-10	Poor reservoir rock
10-15	Fair reservoir rock (general)
15-20	Good reservoir rock
20-25	Very good reservoir rock

Table 3: A Qualitative evaluation of Porosity (Levosen, 1967).

Permeability (mD)	Qualitative Description
<10.5	Poor to fair
15-50	Moderate
50-250	Good
250-1000	Very good
>1000	Excellent

Table 4: A Qualitative Evaluation of permeability (Levosen, 1967).

D. Reservoir volumetric

Table 4 reveals volumetric after modeling. The table shows the bulk volume, and STOIIP at each of the 9 Zones. Zone 7 shows the largest Vb of 88.441250 × 10^6 m^3 and STOIIP of 1.042291 × 10^6 m^3 whereas Zone 1 shows the least Vb and STOIIP, 54.893112 × 10^6 m^3, 0.646922 × 10^6 m^3. The Zao 21 block reservoir zones indicate that hydrocarbon of commercial value thus; the reservoir model could be as input for simulation and performance.

- Porosity and permeability are two distinct properties of the reservoir rock. The correlation analysis between porosity-permeability relationships (Figure 15) resulted in a correlation coefficient of 0.844. This shows good correlation, however, not a perfect one implying that this two quantities are closely related. The fluids are able to permeate through the reservoir rock by passing through the pores it contains, and greater the number and size of pores in the reservoir, easier it is for the fluids to pass through. Thus a higher porosity in the reservoir is likely to be accompanied by higher permeability. However, diagenetic process such as compaction, clay minerals such as montmorrillonite, smectite, illite, etc exist in the formation. This means the effect of these factors at the depth where the reservoir exist is minimal, hence, has small effects on the reservoir quality [43,44].

- Stochastic modeling methods was used due to incomplete information about dimensions, internal (geometric) architecture, and rock-property variability on all scales; the complex spatial distribution of reservoir building blocks or facies; difficult-to-capture rock-property variability and variability structure with spatial position and direction; unknown relationship between property value and the volume of rock used for averaging (scale problem).

Conclusion

1. This work shows the versatility of integrating seismic and well log data for reservoir modeling. The results of the comprehensive petro-physical analysis of 41 wells show one dominant reservoir across the wells in the field at different depth intervals.

2. This Zao 21 reservoir is very promising because of its good porosity and permeability values. The discrete properties gave the knowledge of the facies properties in the field while the continuous properties gave petro-physical properties of the field in terms of porosity, permeability and oil saturation. The volumetric calculation indicates that the reservoir has a reserve of 660 × 10^{4}t. This analysis will

serve as a control of the reservoir during development.

3. The reservoir model of Zao 21 block has provided a better understanding of the spatial distribution of the discrete and continuous properties in the field. The study has developed a geological model for Zao 21 block that can be updated as new data are acquired for field development. The model can be exported for simulation to be run.

4. The study area is a heavy oil reservoir; the petro-physical properties (porosity, permeability and oil saturation) which control the oil storage and movement were modeled.

5. The reservoir properties are controlled by two main faults regimes formed due to tectonic activities in the region.

6. With reference to the model results, porosity, permeability and saturation models of the study area showed promising porosity and permeability properties at the southwestern and northeastern part, however, the oil saturation at the latter part is greater than the former.

7. This study shows a highest porosity value of 28% an average of 15.5%, peak permeability of 550 mD an average of 81 mD and highest oil saturation of 0.55 an average of 11.5%.

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